ENGINEERING CASE LIBRARY

ECL 153

IRRIGATING A RICE FIELD

A Case Study in Hydraulic Engineering

by

Ralph J. Smith
Professor of Electrical Engineering
Stanford University

Charles Keyes received his BS in Electrical Engineering from the University of Wisconsin in June, 1964, and took a summer job with Honeywell in Minneapolis. He returned for a year of graduate study; but before he finished his MS research, he went to work for Collins Radio in Cedar Rapids, Iowa. After seven months with them, he and his wife (who has her MS in Rural Sociology) joined the Peace Corps and went to the Philippines. One of his projects there, a plan to raise water from the river to irrigate rice fields during the dry season, involved economic, political, and cultural factors along with some hydraulic engineering for which he was not well prepared.

ECL 153

PACD, Surigao
Surigao del Norte
April 12, 1966

Professor Henry Richardson
Electrical Engineering Department
University of Wisconsin
Madison, Wisconsin

Dear Professor Richardson:

We arrived in the Philippines in January, and I am assigned as a staff assistant to the Provincial Development Officer of the Presidential Arm on Community Development (PACD) here in Surigao on the northeast tip of the island of Mindanao. The main industries are lumber and copra; most of the agriculture is subsistence farming by small landowners. I work on any projects requiring engineering skills brought to my attention by the fieldworkers. Most of these are civil engineering projects; the demand for my EE talents has been minimal.

Most of my time right now is being spent on an irrigation project near Barrio Magpayang. Just before we arrived, a community development worker was assigned to the municipality of Mainit and set up residence in Magpayang. Through the interaction of the worker and the local Irrigators Association, the project was proposed to the PACD Provincial Office as a means of increasing rice production by permitting two crops of rice per year. Irrigation projects have top priority here, partially due to PACD's own objectives and partially because of the President's emphasis on attaining rice self-sufficiency.

The PACD has found through bitter experience that the barrio people are unable to maintain engine-pump units. This is due mainly to the lack of the necessary technical skills and also to a reluctance to maintain something that is not entirely their own. Therefore, I suggested a water wheel since it is simple in concept and relatively easy to maintain.

My problem is that "water wheel design" was not required in the EE curriculum and I'm not sure just how to proceed. My boss here is putting pressure on me to submit a design and proposal to the regional office for funding. If the project is successful, the income and level of living of the barrio people will be increased and also it will enhance the opportunities for them to learn to work together. Of course the PACD will benefit from good publicity. If the project fails, however, due to faulty design or construction, the suspicions of the people toward PACD and the government will be strengthened.

My problem is complicated by the lack of technical books in Surigao. If you have any suggestions for sources of information on water wheel design, I would appreciate hearing from you.

Sincerely,
Charles Keyes
Charles Keyes

The University of Wisconsin

April 24, 1966

Mr. Charles Keyes
PACD, Surigao
Surigao del Norte
Philippines

Dear Charles:

It was nice to hear from you again and to learn what you are doing. In answer to your question, I suggest that you write to VITA (Volunteers for International Technical Assistance, Inc.) at 230 State Street, Schenectady, New York. VITA is an international association of engineers, scientists, and businessmen who have volunteered their time and skills to assist persons who, like you, are working to raise living standards in developing areas. They believe that one requirement for enduring peace is the elimination of the great disparities in well-being among the peoples of the world. One of them may be able to help you.

It sounds like you've gotten yourself involved in a challenging situation. I'm glad to see that as an EE you are not afraid to tackle CE problems. For possible use in my seminar on engineering in newly developing nations, I'd like to know a little bit more about the project. What is your authority in the PACD and what is your relation to the local civil engineers? What cultural problems do you anticipate in carrying this project through to completion?

Please keep me posted on your progress.

Cordially,

Henry E. Richardson
Professor of Electrical Engineering

PACD, Surigao
Surigao del Norte
May 10, 1966

VITA, Inc.
230 State Street
Schenectady, New York

Dear Sirs:

I am a Peace Corps Volunteer working with a government community development agency in the Philippines. A problem concerning irrigation has arisen here that perhaps you can help us with.

The problem is with pumping water from a river to rice fields. A moderate initial investment can be made (approximately $1,000) since the government will help us with this phase, but maintenance and operating costs must be kept at a minimum. For this reason, along with the fact that electricity is not available, I suggested the use of a water wheel to raise the water.

The pertinent facts are as follows:

Flow of river: 130 cubic feet/sec. (lowest recorded)
Height water must be raised from surface of river: 18 feet
Estimated water needed: 6 cubic feet/sec.

Most types of construction materials are available here or can be easily ordered. Machine shops and welding equipment are also available. The people are also willing to build a small dam and concrete sluiceway to concentrate the river flow.

Would you please study the feasibility of this idea, and if it seems practical, I would very much appreciate a design proposal. If the volume of water that must be pumped is too great, it may be possible to build another wheel downstream. Also, if the height that the water must be pumped is too great to make a water wheel practical, perhaps you would comment on the possibility of using a smaller paddle wheel to drive some other type of pump.

Thank you very much for any help you can give.

Respectfully,
Charles Keyes
Charles Keyes

PACD, Surigao
Surigao del Norte
May 11, 1966

Professor Henry E. Richardson
Electrical Engineering Department
University of Wisconsin
Madison, Wisconsin

Dear Professor Richardson:

Thanks for your letter of April 12. I have written to VITA as you suggested and I hope they can help me out. I'll try to answer your questions as best I can.

Authority. I have no formal authority in PACD. However, since I have been doing all the work on this project and since it is quite unusual, the local PACD office would probably have trouble getting funds for the project without my full support.

Local engineers. The PACD is in theory a coordinating agency and relies on the Bureau of Public Works and other technical agencies to provide voluntary aid on projects. This cooperation is not easy to obtain, but usually can be gotten with sufficient prodding. One of these engineers could do the design, but it will take considerable research since none of them have any working knowledge of water wheels. Since I am not tied down to any specific job, I can spend the necessary time. If we are successful in getting the project funded, I'll try to get one of the government engineers interested and then I can explain to him the important points in constructing it.

Cultural problems. PACD requires that there be an Irrigators Association in the barrio to provide maintenance, paid for by a small fee charged to each Association member receiving water. Unfortunately, the Associations are often unable to work together. Most Filipino business ventures are family affairs, and attempts to get unrelated persons to work together are usually unsuccessful. Probably there will be friction and discontent within the Association as soon as the project is finished, if not before. It will require a respected leader (the President of the Magpayang Association is a doctor who seems to be influential) and a talented fieldworker to help the members over these cultural hurdles.

Actually, I have only visited Magpayang two or three times to survey and to inspect the site and to talk to the Association president, so I don't know too much about this barrio.

I'll write again after I have heard from VITA.

Sincerely.
Charles Keyes
Charles Keyes

VITA VOLUNTEERS IN INTERNATIONAL TECHNICAL ASSISTANCE INC

May 26, 1966

Dr. Gerald T. Ward
Brace Experiment Station
St. James, Barbados

Re: #1993 - IRRIGATION PUMP

Dear Dr. Ward:

Enclosed you will find a copy of a letter from Mr. Keyes. Your resume reflects an interest in this particular kind of problem. We realize that you probably could not take time from your work to develop a design proposal, but we wonder whether you could study the feasibility of Mr. Keyes' proposal.

From our experience, we feel that correspondence between you and Mr. Keyes will produce the most satisfactory results. We would like copies of your letters for our files.

Sincerely yours,

Mrs. William M. S. Richards

(Mrs. William M. S. Richards)
VITA Request Coordinator

Mrs. WMSR/vkm
Enclosure: Mr. Keyes letter - May 10, 1966

Mr. Charles Keyes
PACD, Surigao
Surigao del Norte
Philippines

June 9, 1966

Dear Mr. Keyes:

Re: No. 1993 - IRRIGATION PUMP

In reply to your inquiry to VITA, dated May 10, 1966 -

1. A water wheel may be perfectly feasible.
2. The feasibility depends upon the head or flow rate of river water available, neither of which figures are supplied (refer to accompanying enclosure).
3. I suggest that you check the head which would be available on the site if you built a small dam and concrete sluiceway.
4. A modern design of hydraulic turbine would be more efficient than the water wheel and might be feasible in your economic environment.
5. I have no details of designs of water wheels, very few of which are currently made. I will inquire of Fitz Water Wheel Co., Hanover, Pa., USA, who used to make water wheels and perhaps still do.
6. If the utilization of water power is not feasible you may consider a windmill. What are your average windspeeds like? We are specializing in the development of windmill irrigation equipment. You are no doubt familiar with the multi-bladed fanmill combined with reciprocating water pump which develops about 1/4 horsepower. I would recommend an Australian machine for you: Southern Cross Machinery Pty. Ltd., 22 Young Street, Sydney, N.S.W., Australia. We ourselves have developed a low cost machine for replacing animal power in peasant areas and could send you a "Do-It-Yourself Leaflet" describing the construction. Currently we are developing a 10-horsepower propeller windmill irrigation pumping network, and hope to have the prototype running here in Barbados in August 1966.

If we can be of further assistance, please do not hesitate to contact us.

Yours sincerely

Gerald T. Ward

Gerald T. Ward, Director
Brace Research Institute

Encls.
cc: VITA

WATER WHEELS

Reference:
Hydraulic Turbines by Daugherty, pub. McGraw-Hill, 1913.

General:

Total Head: $H = Z + \frac{v^2}{2g}$ (ft)

where Z = vertical height between entrance and exit of machine (ft)
v = velocity of flow of water entering machine (ft per sec)
g = 32.2 (ft per sec per sec) = acceleration due to gravity

Water Driving Power: $P_w = \frac{WH}{550}$ (horsepower)

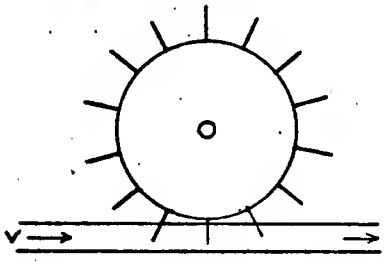
where W = weight rate of flow (lb per sec)

Shaft Output Power: $P_o = E \times P_w$ (horsepower)

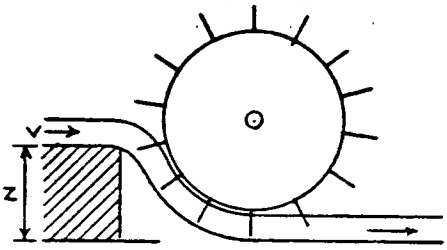
where E = overall efficiency

Types of Wheel

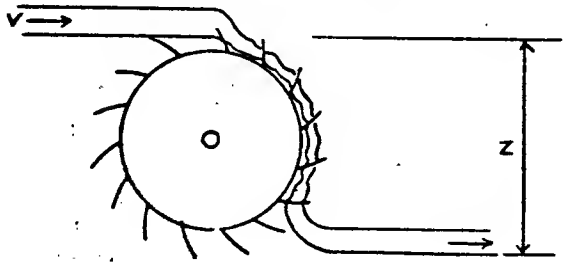
1. Undershot: E = 30%



2. Breast Wheel: E = 60%



3. Overshot: E = 80%



No. 1993 - IRRIGATION PUMP

Given:

Minimum River Flow: $W = 130$ cusecs $= 8{,}120$ lbs per sec

Irrigation Water:

head required $= 18$ ft

flow required $= 6$ cusecs $= 375$ lb per sec

Calculation:

Irrigation water horsepower required $=$

$$\frac{18 \times 375}{550} = 12.27 \text{ hp}$$

Assume pump efficiency $= 70\%$

Output power of water wheel required:

$$P_o = \frac{12.27}{0.7} = 17.55 \text{ hp}$$

Assume undershot water wheel efficiency: $E = 30\%$

Water driving power required: $P_w = \frac{17.55}{0.3} = 58.5$ hp

Total driving water head required:

$$H = \frac{550 P_w}{W} = \frac{550 \times 58.5}{8120} = 3.96 \text{ ft}$$

but $H = Z + \frac{v^2}{64.4}$

The 4 ft head may therefore be obtained from a drop in elevation of the water stream of 4 ft or from a velocity of river water flow of $v = \sqrt{(64.4 \times 4)} = 16$ ft per sec or a combination of the two.

PACD, Surigao
Surigao del Norte
June 23, 1966

Dr. Gerald T. Ward
Brace Experiment Station
St. James, Barbados, West Indies

Dear Dr. Ward:

I was very happy to receive your letter of June 9 and your suggestions for our irrigation project.

I appreciate your willingness to check with the Fitz Water Wheel Co. Since writing to VITA, I have had an opportunity to visit the proposed site again and I have some better data for you. The minimum river flow measured 80 cu ft/sec. during the past dry season; how low it gets other years is a matter of conjecture. During the rainy season the high water mark is at the top of the bank.

The amount of water needed for the approximately 250 hectares to be irrigated should be 8 cu ft/sec. The bank height above the present water level is about 12 ft; to allow for a stilling basin and perhaps a slightly elevated canal, I would suggest that you design for 15 ft of lift plus friction loss. The driving head is under our control since a dam must be built to provide it; however, for reasons of economy, I think it should be kept lower than 6 ft high. One idea I had was to add some lifting buckets right beside the driving blades. Do you have any other suggestions for lifting the water?

I appreciate your comment about the hydraulic turbine being more efficient, but I think that would be too difficult for the local craftsmen to build and I know we couldn't afford to import one. The idea of fanmills is intriguing, but I'm afraid that maintenance of windmills on individual farms would be impossible in view of the complete lack of mechanical experience on the part of the barrio people.

Thanks again for your willingness to help me on this project. I hope the above information is sufficient for your planning. Please let me know if there is any additional information that you need.

Sincerely,

Charles Keyes

Charles Keyes

BRACE [illegible]

PHONE [illegible]
OUR REF
YOUR REF

BRACE [illegible]
[illegible]
WEST INDIES

Mr. Charles Keyes
PACD, Surigao
Surigao del Norte
Philippines

July 19, 1966

Dear Mr. Keyes:

This is to acknowledge receipt of your letter dated June 23, 1966, since which time I have given careful thought to the proposed project with the following conclusions:

1. This is quite a large-scale undertaking and it would be disastrous if it were technically unsuccessful, both as regards our prestige and also the waste of money and effort.

2. The whole project should therefore be very carefully thought out beforehand and it might be advisable to first build a working model. This would also provide a useful demonstration to assist you in obtaining willing helpers for the actual construction of the full-scale installation.

3. The mechanical equipment falls into two distinct categories; i.e., a means of obtaining power from the stream water and a method of utilizing this power to lift irrigation water.

4. I believe that a suitably designed water wheel would provide a satisfactory means of obtaining the power, and am willing to make a skeleton design which you could use as a basis for detailed construction. Preliminary estimates are as follows for a Poncelet type undershot water wheel:

Available head = 4.5 feet

Approach flume to wheel to be rectangular, 7 ft wide, depth of water about 6 in., with a 10 degree slope.

Water wheel outside diameter 20 ft, radial depth of blades 3 ft, width of blades 7 ft, number of blades 60. The blades would be of mild steel with circular curvature, detailed design to be given later. The wheel would run at about 9 revolutions per minute with an efficiency of close to 70 per cent, using about 55 cubic feet per second of river water. The water channel passing by the blades would have to be

accurately circular, in a 15-degree segment on each side of bottom dead center and would have a maximum clearance of 1/2 inch between the channel walls and the blades.

5. I do not advise incorporating the lifting buckets for the irrigation water with driving water wheel as the buckets would interfere seriously with the fluid flow pattern at the wheel blades and ruin the efficiency.

6. Regarding the irrigation lifting device I suggest one of two alternatives:

(a) The lift could be obtained by attaching horizontal cantilever arms to the side of the water wheel, suitably shaped buckets being secured to the arms. The buckets, travelling at about 7 miles per hour, would scoop water from a separate sump, completely distinct from the channel in which the water wheel works and lying to the side of it. This sump would be supplied by water from the dam, the buckets being forced about three feet below the water surface to ensure filling. The buckets could form a continuous line around the inside circumference of a cantilever wheel as in the attached sketch. The buckets would be about 6 ft wide, 1 ft long and average 4 in. deep. The profile would have to be decided carefully so as to ensure that the correct volume of water was scooped up out of the sump and that the water dropped out of the bucket over a short part of the circumference (say, 40 degrees) at the top of the lift. This would not present any difficulty. The enclosed sketch shows one way of achieving the desired result while keeping the resistance of the buckets to fluid drag in the sump at a low value. A better arrangement would be to have two sets of buckets, each 3 ft wide, one on each side of the water wheel so as to avoid out of balance forces.

This type of bucket lift may be the most suitable for you. However, it is heavy and slow moving and would require a lot of sheet metal. This is a very powerful plant (about 20 horsepower) for a peasant style application and is liable to be very heavy and slow moving.

(b) The other alternative would be to gear up the water wheel drive from 10 rpm to, say, 700 rpm and use an orthodox "off-the shelf" low lift pump. A propeller type pump could be obtained for about US $1,200. I have located a "Cascade" pump, 16 in. diameter, which will provide over 3,600 US gallons per minute against a 10 ft head (from reservoir to irrigation channel) when running at 875 rpm. You could arrange a very inexpensive drive by using the rear axle of a scrapped truck. The wheels, say, 30 in. diameter, could run on the outside of the water wheel as indicated in the sketch. With a 25 ft. diameter water wheel and a 7-to-1 differential crown-wheel-to-pinion ratio, the speed of the truck propeller shaft would

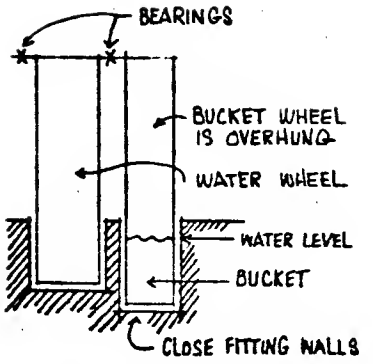
be 10 rpm X (25/2.5) X 7; i.e., 700 rpm. The propeller shaft would then give about 20 horsepower at 700 rpm, which could be used for alternative village power (i.e., electric lights) when irrigation is not required. If you wish to use this principle, please look for a suitable truck rear end available locally with small wheel diameter and maximum crown-wheel-pinion ratio for the biggest shaft speed, and give me details of wheel outside diameter (i.e., outside diameter of tires), crown-wheel-pinion-gear ratio, width of tires and distance between tire center lines; I can then select water wheel dimensions to suit.

7. Perhaps you would consider these suggestions in the light of local conditions, and give me your final conclusions so that I may go ahead with a firm design.

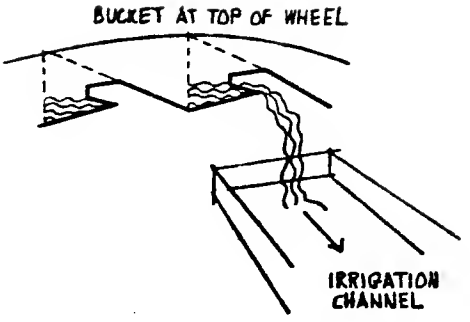
8. Please ensure first that alternative methods, e.g., diesel pumping sets, would not be cheaper.

Yours sincerely,
Gerald T. Ward
Gerald T. Ward
Director
BRACE RESEARCH INSTITUTE

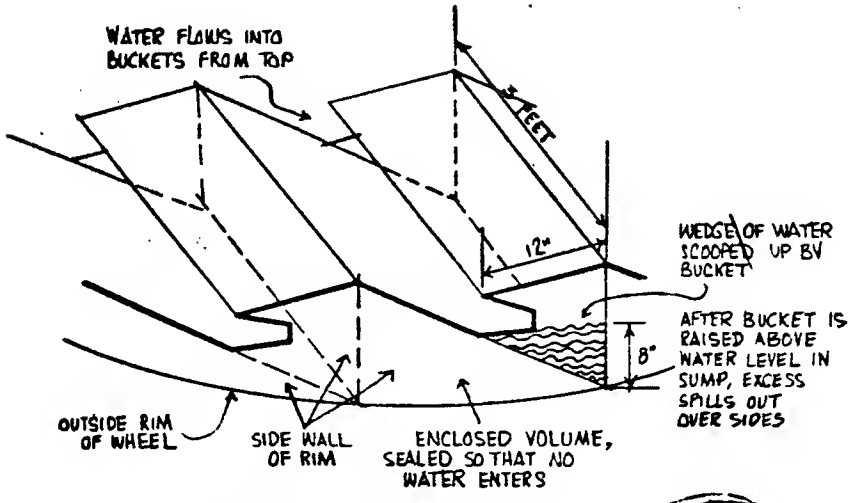
Encls.



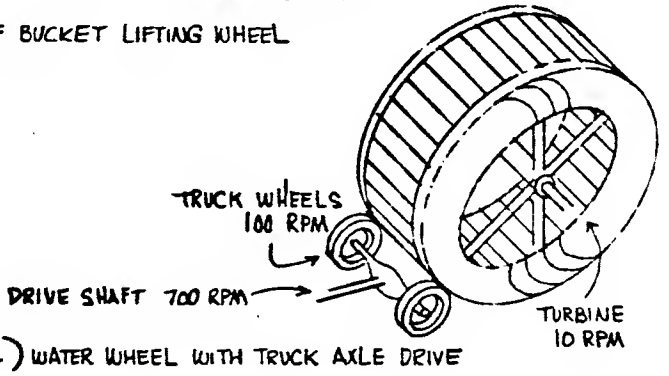
(a) POWER AND LIFTING WHEELS



(b) WATER DISCHARGE



(c) DETAILS OF BUCKET LIFTING WHEEL



(d) WATER WHEEL WITH TRUCK AXLE DRIVE

FITZ WATER WHEEL COMPANY

MANUFACTURERS OF
WATER WHEELS AND HYDRAULIC TURBINES
WIRE WEAVING MACHINERY
HANOVER, PA., U.S.A.

DONALD C. WISENSALE
PRESIDENT

July 22, 1966
Via air mail

Brace Research Institute of McGill University
Brace Experiment Station
St. James, Barbados, West Indies

Attention: Gerald T. Ward, Director
Brace Research Institute

Dear Mr. Ward:

Thanks for your letter of July 15th requesting information on the Poncelot Wheel for the Peace Corps work in the Philippines. We are sorry to have to tell you that at the time of this writing there is every indication that the Fitz Water Wheel Company will be going out of business in the near future. We, therefore, will not quote on a wheel since we would probably not be able to furnish it.

We have checked over your figures and find that to pump the amount of water required you would need about 15 horsepower. We have checked our tables and find that a Poncelot Wheel 16 ft diameter by 5½ ft wide using 3,300 cubic feet of water per minute should develop approximately 20 horsepower under 4½ ft head. The radial vanes or buckets should be made curved and they should be about 28 to 30 in. deep. The water entering the wheel should pass thru a gate whose opening is 7¼ in. high and about 5 ft wide. If we were to build this wheel we would make the housings or side pieces out of No. 10 gauge steel and the buckets out of No. 12 gauge steel.

Since you say this gentleman is asking for advice to construct his own wheel we hope this information will be of some help to him. Ordinarily, we would make such a wheel in 8 sections using 8 spokes on each side of the wheel. The spokes should be not less than ½ in. by 5 in. and the shaft should be 5½ to 6 in. in diameter.

We trust that this information will be of some help to your friend and that he is successful in constructing a wheel to pump water for him.

Very truly yours,
FITZ WATER WHEEL COMPANY
D. C. Wisensale
Per (D. C. Wisensale)

DCW.M.

PACD, Surigao
Surigao del Norte
September 28, 1966

Professor Henry E. Richardson
Electrical Engineering Department
University of Wisconsin
Madison, Wisconsin

Dear Professor Richardson:

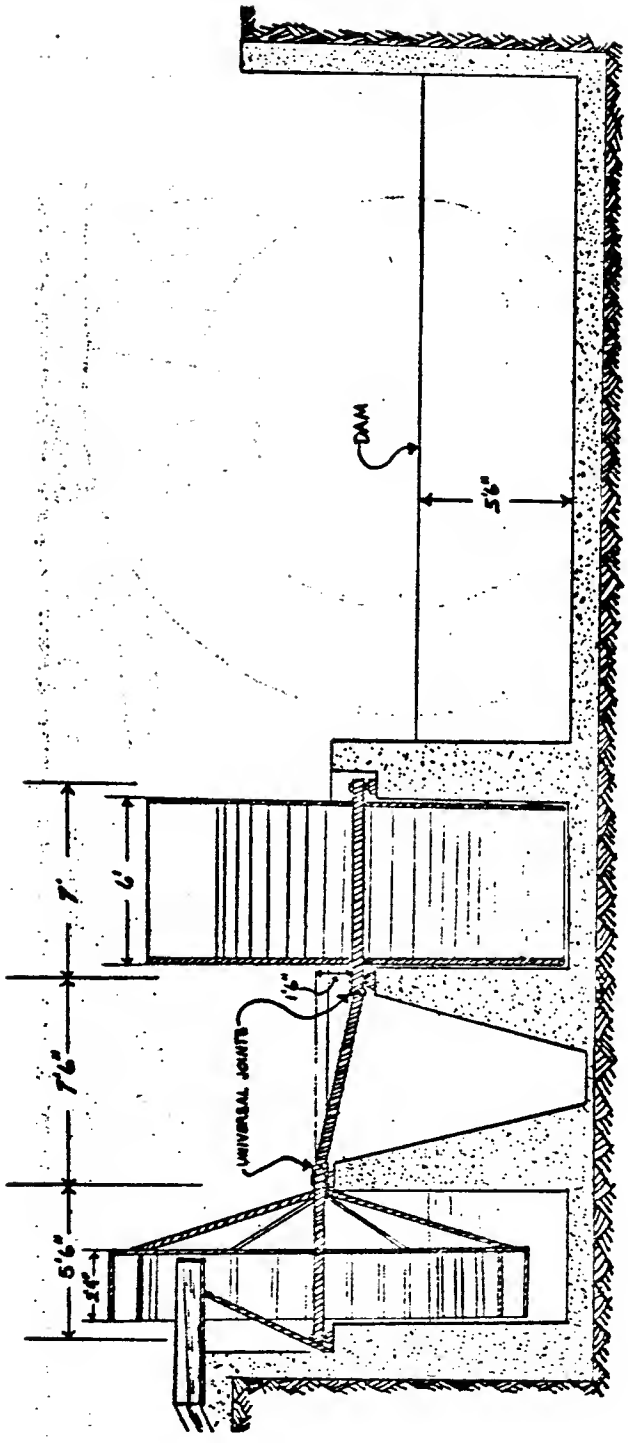
After some long delays the water wheel design I was working on last year is nearly complete. Dr. Ward was away from his office a lot last year, and early this year his headquarters was transferred from Barbados to Montreal. However, he did have time to do some preliminary design calculations based on HYDRAULICS by Bovey (published by Wiley in 1906), and he sent me a copy of a specimen design for a Poncelot water wheel (Bovey, pp. 424-437). He also sent me a copy of a letter from probably the last company in the USA to manufacture water wheels.

Using that information I have proceeded with the design shown on the enclosed sketches. I had located an available truck axle as he suggested, but I had trouble working out the design details. Two of my main problems were how to construct the surfaces on the wheel on which the tires would run and how to develop the large force between tires and wheel so that an adequate frictional force could be obtained. The coefficient of friction would be quite low since the surface would be wet.

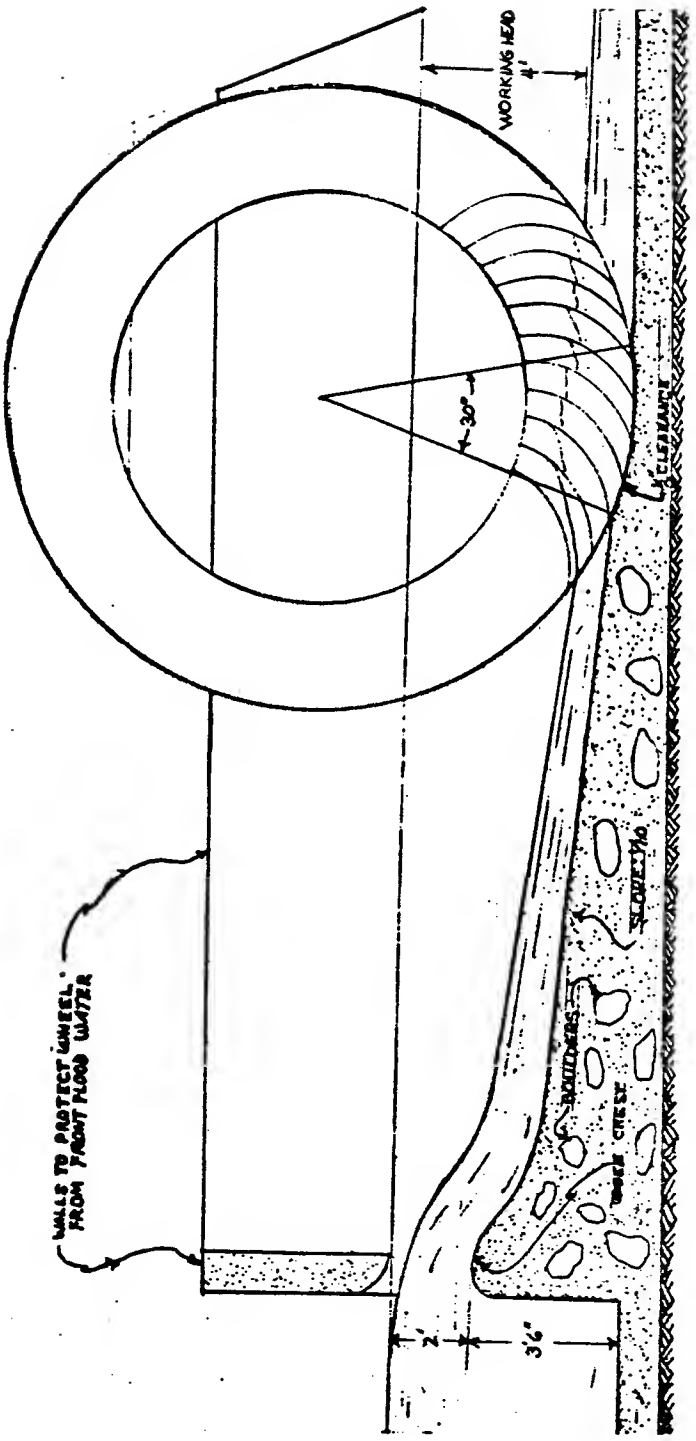
As the sketches show, my present scheme for lifting the water is to use an accompanying wheel directly coupled to the driving wheel. The main advantage of this scheme is the easy maintenance and repair it would afford. This is precisely why a water wheel was considered in the first place.

The design must be completed before I leave in December or it will not, in all probablilty, be implemented. As soon as I'm satisfied with the last details, the design will be submitted to the PACD regional office for funding. If and when funds are released, the construction can be supervised by a local civil engineer, of which there are many. By that time I expect to be back at Wisconsin finishing my master's thesis and taking a few refresher courses.

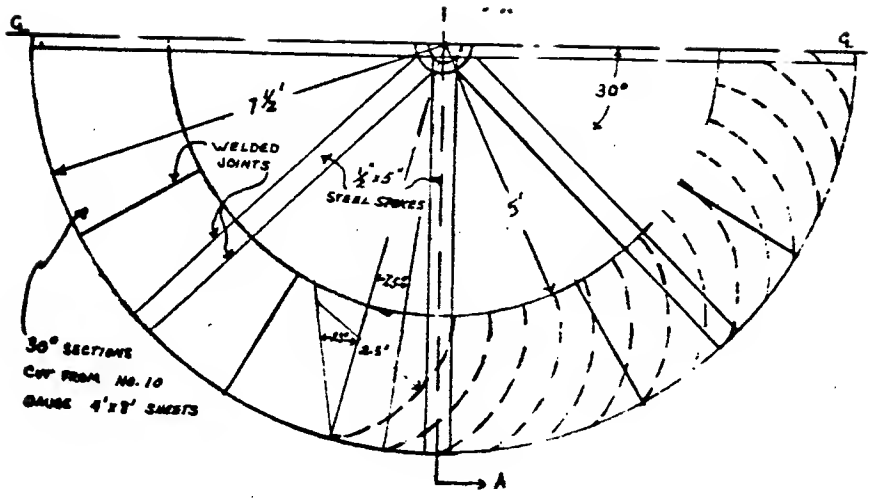
Sincerely,
Charles Keyes
Charles Keyes

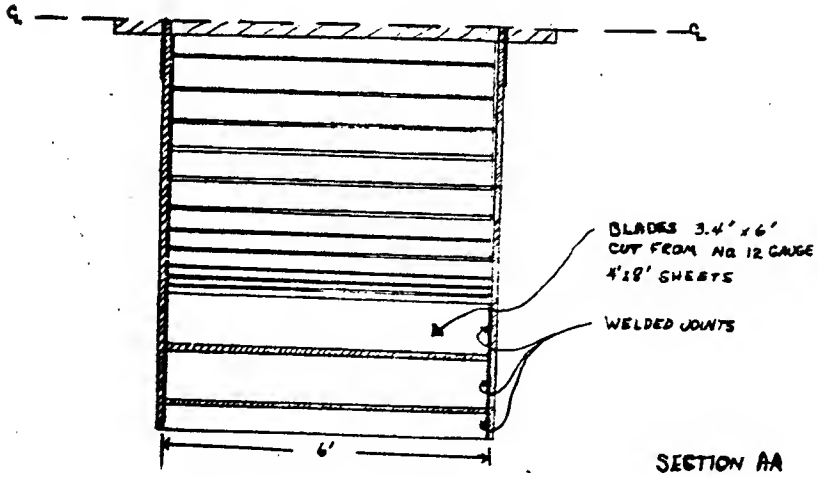


Section through both wheels, looking upstream

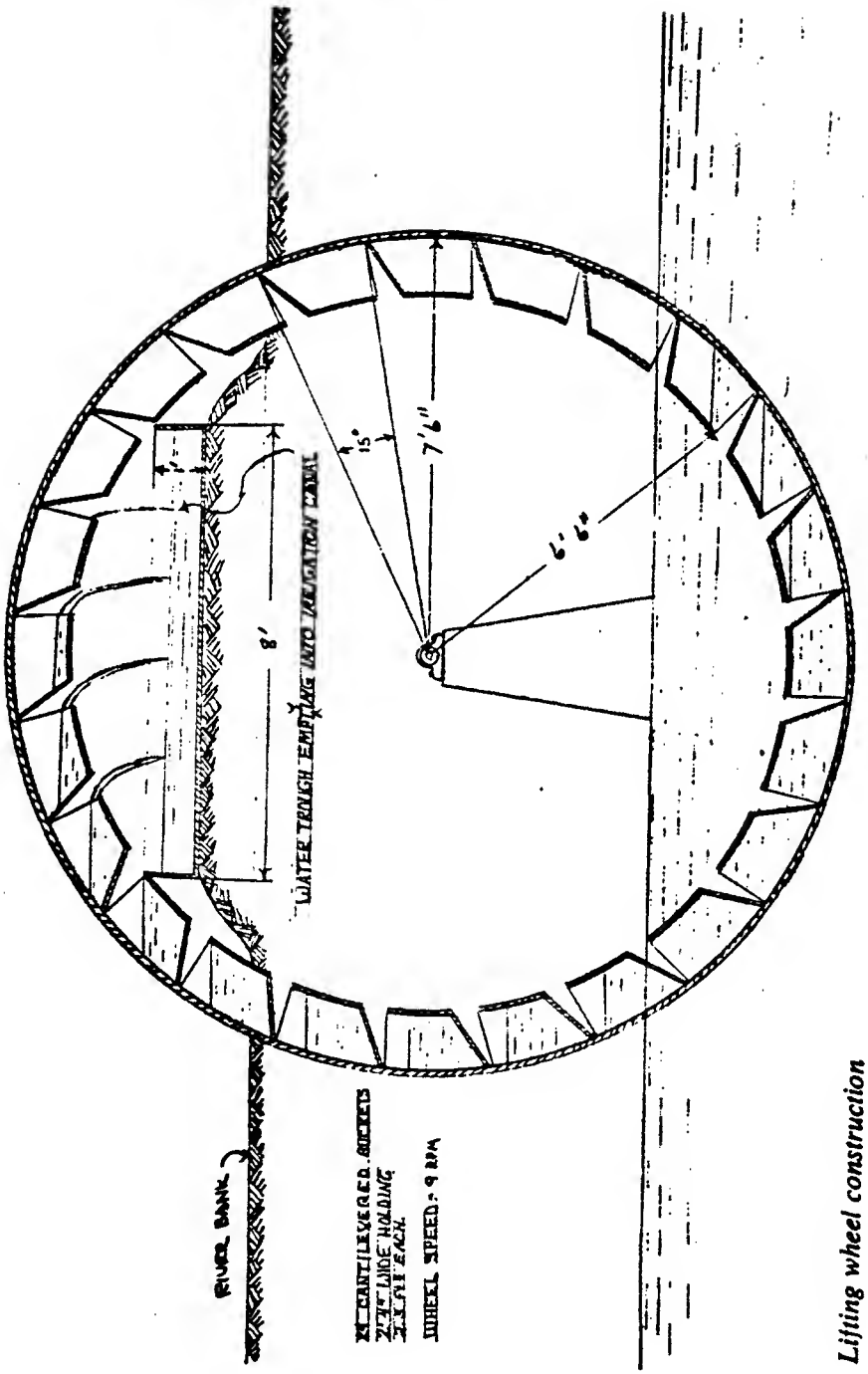


Section through power wheel and sluice





Power wheel construction



Lifting wheel construction